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# BMJ Open

## **I-ACT: Integrated study on effect of Activity on ComplicaTions in pregnancy – study protocol of a multi-ethnic prospective cohort study**

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9 I-ACT: Integrated study on effect of Activity on ComplicaTions in  
10 pregnancy – study protocol of a multi-ethnic prospective cohort study  
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## Abstract

**Introduction:** Physical activity (PA) during first 20 weeks of pregnancy may lower risks of gestational diabetes mellitus (GDM) and gestational hypertension (GH), though evidence of association remains inconclusive. Current studies rely heavily on subjective assessment of PA levels. Wearable activity trackers provide a convenient and objective surrogate index for PA validated by evidence-based steps/day categorization along a physical inactivity/activity continuum. I-ACT primarily aims to examine objectively measured PA levels and patterns in first and second trimesters of pregnancy and the association with GDM and/or GH in Singapore, a multi-ethnic Asian population. Secondary aims include investigating the bio-socio-demographic factors associated with sedentary behavior, and association of early pregnancy PA level with maternal weight at 6 weeks post-delivery. Results may facilitate identification of high-risk mothers-to-be and formulation of interventional strategies.

**Methods and analysis:** Prospective cohort study that will recruit 408 women at first antenatal visit at <12 weeks gestation. Baseline bio-socio-demographic factors and PA levels assessed by participant characteristics form and the International Physical Activity Questionnaire (IPAQ) respectively. An activity tracker (Fitbit) will be provided to be worn daily from date of recruitment to end of 20 weeks gestation. Tracker-recorded data will be synchronized with an application on participant's smartphone. Compliance will be reinforced with fortnightly reminders. After 20 weeks, a second IPAQ and a feedback form will be administered. GDM screened at 24-28 weeks gestation. GH diagnosed after 20 weeks gestation. Maternal weight assessed at 6 weeks post-delivery. Appropriate statistical tests will be used to compare continuous and categorical PA measurements between first and second trimesters. Logistic regression will be used to analyse associations.

**Ethics and dissemination:** Ethical approval obtained from the Centralised Institutional Review Board of SingHealth (reference 2017/2836). Dissemination of results will be via peer-reviewed research publications both online and in print, conference presentations, posters, and medical forums.

(299 words)

**Keywords:** Physical activity, gestational diabetes mellitus, pregnancy-induced hypertension, pregnancy

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3 Article summary

4 **Strengths and limitations of this study**

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- Prospective cohort study of a multi-ethnic Asian population
  - Objective measurement of PA levels and patterns in early pregnancy
  - Data collection designed to minimize recall bias
  - Participant non-compliance despite reinforcement measures
  - Participants' unfamiliarity with wearable activity tracker and mobile application despite education at recruitment

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## Introduction

Physical activity (PA) is defined as any bodily movement produced by skeletal muscles that results in energy expenditure<sup>1</sup>. Current recommendations encourage women with uncomplicated pregnancies to continue or initiate safe physical activities in pregnancy<sup>2</sup>. More specifically, the CDC recommends 30 min/day for five days each week of moderate-intensity aerobic activity, which can be met by walking<sup>3</sup>. Concerns about safety have been refuted by literature demonstrating that moderate exercise in low-risk pregnancy improves maternal well-being without associated risks of birth weight reduction or preterm birth<sup>4</sup>.

Physical inactivity or sedentary behavior in early pregnancy (<20 weeks gestation) is a potential modifiable risk factor for two common obstetric complications, gestational diabetes mellitus (GDM) and gestational hypertension (GH). GDM is defined as carbohydrate intolerance that develops during pregnancy<sup>5</sup>. It complicates 1.8-25.1% of pregnancies worldwide depending on country and definition, with South-East Asia having the second highest prevalence at 8.1-18.3<sup>6</sup>. Approximately 8-20% of pregnancies are affected in Singapore<sup>7</sup>. Overall prevalence of GH, otherwise known as pregnancy-induced hypertension, is estimated at 10-12%<sup>8,9</sup>, though the local incidence has not been established. Perinatal sequelae of GDM and GH include macrosomia, neonatal hypoglycemia, preterm birth, intrauterine growth restriction (IUGR), and low APGAR scores. Both metabolic disorders are also proven risk factors of future type 2 diabetes<sup>10</sup>.

Current literature investigating the association between PA in early pregnancy and the development of GDM has shown a significant risk reduction of up to 24%<sup>11-14</sup>, though a few other studies have found a null association<sup>15,16</sup>. The association with GH is even less clear from the limited literature available<sup>17-20</sup>. All these studies utilised questionnaires as a measurement of PA. Studies that incorporate an objective means of measurement have been scarce<sup>21,22</sup>, which may partially explain the inconclusive evidence of association thus far. A Norway-based study investigating objectively recorded PA in early pregnancy and GDM reported that the adjusted odds ratio for GDM decreased 19% with every 3159 step-increase per day<sup>21</sup>. Based on these existing studies, physical inactivity in early pregnancy is a modifiable risk factor worth targeting

This is especially so in the Asian population. PA during first half of pregnancy has been shown to be low in an Asian urban setting<sup>23</sup>, and similarly lower when compared to non-Asian counterparts<sup>22,24</sup>. In Singapore, no published study on objectively measured PA levels in pregnancy could be found, and studies on association of subjectively-measured early pregnancy PA levels with both obstetric complications are rare. Padmapriya *et al.* investigated the change in PA levels from a pre-pregnancy to pregnancy state using a structured self-constructed questionnaire administered at 26-28 weeks gestation scored based on the International Physical Activity Questionnaire (IPAQ) short form<sup>25</sup>. The same study group further reported that a higher PA during the first 6 months of pregnancy was associated with lower prevalence of GDM, especially among overweight/obese women<sup>26</sup>. However, the utilisation of a questionnaire at 26-28 weeks gestation that relied on recall of PA levels during first 6 months of pregnancy and the year before subjected the results to a high level of recall bias. Therefore, the paucity of local research on objectively-measured PA levels in early pregnancy and association with obstetric metabolic outcomes warrants additional prospective studies.

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3 As evident from existing studies, current assessment of pregnancy PA levels relies heavily on  
4 subjective, self-reporting questionnaires deemed to be the most feasible method with the  
5 absence of a gold standard and clear guidelines<sup>27</sup>. The inclusion of more objective  
6 measurements is being advocated<sup>28</sup>. Consumer wearable activity trackers operate through a 3-  
7 axis accelerometer, providing an alternative convenient and objective means of assessing PA  
8 levels during pregnancy. The accuracy, reliability and efficacy of wearable activity trackers  
9 in various health programs have been validated<sup>29-32</sup>. Steps per day categorization along a  
10 physical inactivity/activity continuum based on CDC recommendation has also been  
11 elucidated, with 5000 (sedentary) and 10,000 (active) being the primary anchor points<sup>33</sup>. The  
12 correlation between steps per day and activity counts per day, from which activity intensity  
13 and duration were derived, was proven to be positive and strong, thus validating its use as an  
14 index for PA<sup>34</sup>. Step count estimated by Fitbit activity trackers in particular has also been  
15 validated in a separate study<sup>35</sup>.

18 Through the use of both Fitbit activity trackers and the IPAQ, this prospective multi-ethnic  
19 cohort study primarily aims to investigate the PA levels and patterns in early pregnancy (1st  
20 trimester and 2nd trimester up to 20 weeks gestation), as well as the effect of PA in early  
21 pregnancy on development of GDM and/or GH. Secondary aims include assessing the bio-  
22 socio-demographic factors associated with sedentary behavior, and examining the association  
23 between early pregnancy PA level and maternal weight at 6 weeks post-delivery.  
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## Methods and analysis

### **Study design**

In this prospective cohort study, pregnant women will be recruited at outpatient clinics in KK Women's and Children's Hospital, a major public hospital in Singapore that sees a high volume of obstetrics & gynaecology consultations.

### **Recruitment and eligibility criteria**

All obstetricians running outpatient general obstetrics & gynaecology clinics will refer suitable candidates for recruitment. All recruitment will be done via face-to-face contact by the research team.

Inclusion criteria are singleton pregnancy, first antenatal visit less than 12 weeks gestation, and ages between 21 and 50 years old inclusive. Exclusion criteria are severe medical and/or psychological co-morbidity (including New York Heart Association (NYHA) class IV heart failure, end-stage renal disease, assistive device-dependent for mobility, cognitive impairment, and loss of rational thinking), and skin conditions (including contact dermatitis, pemphigus vulgaris and bullous pemphigoid) precluding the wearing of activity trackers.

### **Power analysis**

Given that prevalence of GH has not been investigated in Singapore, GDM prevalence is used instead. Assuming that GDM proportion is 17.6%<sup>36</sup> and that PA can reduce risk of GDM by 30%, a sample of 367 mothers will be required at 80% power and 5% level of significance. Assuming a dropout rate of 10%, a sample of 408 mothers will be recruited into the study.

### **Participant timeline**

Recruitment is at first antenatal visit less than 12 weeks gestation, during which Fitbit education, International Physical Activity Questionnaire (IPAQ) and participant characteristics form are done (Fig. 1). PA level monitoring occurs henceforth until end of 20 weeks gestation inclusive. The standard 4-weekly antenatal visits will continue during this period. After 20 weeks gestation, a second IPAQ and a feedback form are administered either at regular antenatal visits before 24 weeks gestation, or over the phone/email. Routine GDM screening takes place between 24 and 28 weeks gestation. The final follow-up occurs at the 6th week after delivery to obtain participants' weight.

### **Ensuring compliance**

Approaches to enhance compliance include reinforcing the importance of commitment to wearing the activity trackers daily at the time of recruitment, and making fortnightly follow-



up calls up until 20 weeks gestation. Compliance will also be recorded as part of Fitbit use assessment in the participant feedback form at the end of 20 weeks gestation.

## Outcome measures

Primary outcomes include the following:

- GDM – diagnosed if the following threshold value at any time point is exceeded after a 75 g oral glucose tolerance test (OGTT) between 24 and 28 weeks gestation based on the International Association of Diabetes and Pregnancy Study Groups (IADPSG) criteria: fasting venous plasma glucose of  $\geq 5.1$  mmol/L, 1-hour venous plasma glucose of  $\geq 10.0$  mmol/L, and 2-hour venous plasma glucose  $\geq 8.5$  mmol/L<sup>37</sup>.
- GH – diagnosed as new onset hypertension (systolic blood pressure  $\geq 140$  mmHg and/or diastolic blood pressure  $\geq 90$  mmHg) measured on two occasions at least four hours apart after 20 weeks gestation in the absence of proteinuria or new signs of end-organ dysfunction<sup>38</sup>.

Secondary outcomes include the following:

- Weight at 6 weeks post-delivery
- Weight gain in pregnancy
- Intrauterine growth restriction (IUGR)
- Preterm birth (GA <37 weeks)
- Macrosomia (BW >4.5kg)
- Neonatal hypoglycemia (glucose <2.5 mmol/L)
- Pre-eclampsia
- APGAR scores

## Data collection

### *Research participant characteristics form*

Sociodemographic data to be assessed include marital status, educational level, household income, type of housing, working status during pregnancy, smoking status, and alcohol consumption. Medical history including pre-pregnancy height and weight, parity, history of infertility treatment, existing chronic illnesses, history of GDM and/or GH, family history of DM, and reasons behind potential PA restriction during early pregnancy will also be collected.

### *Fitbit activity tracker and mobile application*

At recruitment, each participant is given a wristband activity tracker (Fitbit) that will be connected via Bluetooth to a Fitbit application downloaded onto her smartphone. Education on device and application will be carried out. The tracker is worn daily from recruitment to end of 20 weeks gestation inclusive, except during bathing or water activities. Participants are advised to synchronize the tracker data at least once a week. For data to be valid, wear-time must be at least 4 days per week (including one weekend day) and at least 10 hours per day.

Steps per day will be recorded by the tracker. Data will be reported as continuous and categorical variables. Continuous variables include mean weekday and weekend steps per day and mean steps per day in first and second trimesters. Categorical variables include classification into a CDC recommendation-based steps per day physical inactivity/activity continuum defined as follows: (1) <5000 (sedentary); (2) 5000-7499 (low active); (3) 7500-9999 (somewhat active); (4) 10,000-12,499 (active); and (5)  $\geq 12,500$  (highly active)<sup>33</sup>.

### ***International Physical Activity Questionnaire (IPAQ)***

The IPAQ long version will be self-administered during the first visit at less than 12 weeks gestation in the first trimester and again between 20-24 weeks gestation in the second trimester. It is a set of 4 questionnaires assessing 5 activity domains (occupation, transportation, household, leisure, and sedentary) independently in the past 7 days, and may be administered via self or telephone<sup>39</sup>. Well-established and validated in adults aged 15-69 years, it is available in both English and Chinese<sup>40,41</sup>. It has been used in studies involving pregnant women<sup>28,42</sup>.

Data will be reported as continuous and categorical variables. Continuous variables include median MET-minutes per week (MET-min/wk) and interquartile ranges computed for each domain, subdomain (walking, moderate-intensity PA and vigorous-intensity PA) and overall total PA. MET or metabolic equivalent is a unit that measures energy expenditure in multiples of the resting metabolic rate<sup>43</sup>. Categorical variables include classification into low, moderate, high levels of PA according to the IPAQ scoring protocol.

### ***Medical record data***

Additional data to be collected include ethnicity, weight changes during pregnancy, weight at 6 weeks post-delivery, obstetric outcomes of GDM, GH, preeclampsia and IUGR, and neonatal outcomes comprising APGAR scores, preterm birth, macrosomia, and neonatal hypoglycemia.

### ***Participant feedback form***

After the end of 20 weeks gestation, experience with the activity tracker and mobile application in terms of usability and troubleshooting will be evaluated. Compliance level will be quantified by number of days per week.

### ***Statistics***

Descriptive statistics of PA levels in the 1st and early 2nd trimester will be presented. Mean steps per day and median MET-minutes per week between semesters will be compared using paired Student's t-test and Wilcoxon signed-rank test respectively. McNemar's test will be used to compare sedentary behavior between semesters. Similar tests will be used to assess for a difference in PA levels between weekdays and weekends.

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3 Logistic regression will be used to evaluate bio-socio-demographic factors associated with  
4 sedentary behavior, and the effect of early pregnancy PA on GDM and/or GH.

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6 Statistical analyses will be performed using IBM SPSS Statistics version 23.0 (IBM Corp.,  
7 Armonk, N.Y., USA). *P* values of <0.05 will be considered statistically significant.

### 8 9 10 **Safety parameters**

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12 Adverse effects and device monitoring will be carried out at the subsequent 4-weekly routine  
13 prenatal visits. Any adverse skin reaction to the wristband will be recorded. Participation will  
14 be stopped at any time the Principal Investigator decides that continuing on could be harmful  
15 to the participant.

### 16 17 18 **Data management**

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20 All data will be coded for confidentiality. Hardcopy data will be stored at the research site  
21 under lock and key. Electronic data can only be accessed and retrieved from the secured  
22 website by the participant and research team. All data obtained will be entered into and stored  
23 on the institution Research Electronic Data Capture (REDCap) system, a centralised secured  
24 data management server with password access. Data integrity monitoring will be carried out  
25 monthly by the principal investigator and co-investigators if deemed necessary.

### 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 **Ethics and dissemination**

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3 Ethical approval was obtained from the Centralised Institutional Review Board of SingHealth  
4 (reference 2017/2836). Informed written consent will be sought from all participants.  
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6 Results from this study will be submitted to the funding organization and peer-reviewed  
7 journals for consideration of publication both online and in print. Results will also be  
8 presented at relevant meetings, conferences and medical forums in either oral or poster  
9 formats.  
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## 55 Conclusion

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3 The I-ACT study aims to be the first comprehensive study objectively evaluating the PA  
4 levels and patterns in early pregnancy, and their association with GDM and/or GH in the  
5 multi-ethnic population of Singapore. In addition to addressing these important scientific  
6 knowledge gaps, from a clinical perspective, the study itself may increase awareness of PA  
7 during early pregnancy while demonstrating the potential of wearable activity trackers as an  
8 objective measure of PA in health research. More importantly, we hope the results of the  
9 study facilitate the identification of high-risk mothers-to-be for targeted intervention, and  
10 help formulate strategies for interventional efforts.  
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### Author statement

MC was involved in all aspects of the study from conception, design, recruitment and manuscript writing. KHT and SBA provided critical review of the design and writing. As

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3 Principle Investigator, SBA takes overall responsibility for the work. All authors agree to be  
4 accountable for their work.  
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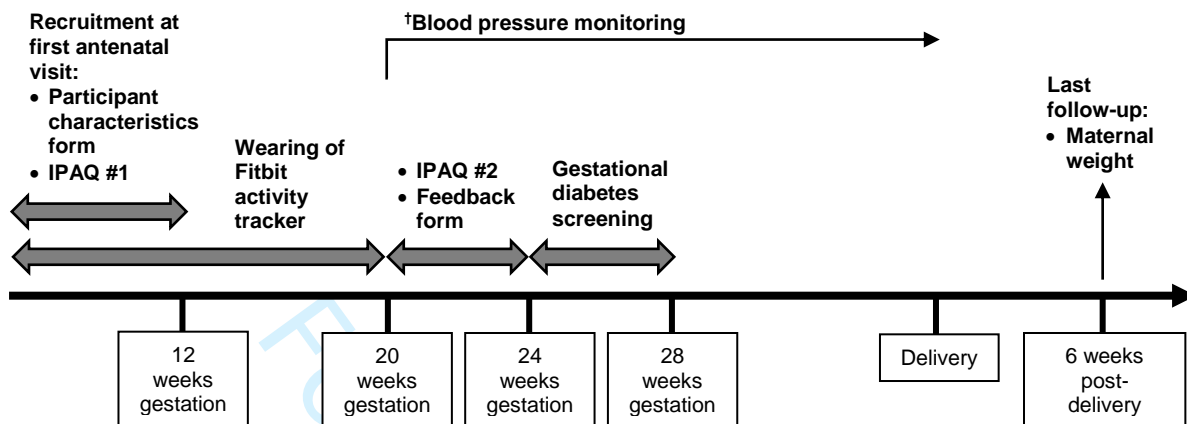
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16 Conflict of interests

17 The authors declare no potential conflicts of interest with respect to the authorship and/or  
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†Participants will continue to attend routine antenatal visits throughout the study period during which blood pressure monitoring will be done

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# BMJ Open

## I-ACT: Integrated study on effect of Activity on Complications in pregnancy – study protocol of a multi-ethnic prospective cohort study

Journal:	<i>BMJ Open</i>
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Secondary Subject Heading:	General practice / Family practice, Diabetes and endocrinology
Keywords:	Diabetes in pregnancy < DIABETES & ENDOCRINOLOGY, Maternal medicine < OBSTETRICS, PREVENTIVE MEDICINE, PRIMARY CARE

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Manuscripts

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10 **3** I-ACT: Integrated study on effect of Activity on ComplicaTions in  
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13 **4** pregnancy – study protocol of a multi-ethnic prospective cohort study  
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3 38 Abstract  
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5 39 **Introduction:** Physical activity (PA) during first 20 weeks of pregnancy may lower risks of  
6 40 gestational diabetes mellitus (GDM) and gestational hypertension (GH), though evidence of  
7 41 association remains inconclusive. Current studies rely heavily on subjective assessment of PA  
8 42 levels. Wearable activity trackers provide a convenient and objective surrogate index for PA  
9 43 validated by evidence-based steps/day categorization along a physical inactivity/activity  
10 44 continuum. I-ACT primarily aims to examine objectively measured PA levels and patterns in  
11 45 first and second trimesters of pregnancy and the association with GDM and/or GH in  
12 46 Singapore, a multi-ethnic Asian population. Secondary aims include investigating the bio-  
13 47 socio-demographic factors associated with sedentary behavior, and association of early  
14 48 pregnancy PA level with maternal weight at 6 weeks post-delivery. Results may facilitate  
15 49 identification of high-risk mothers-to-be and formulation of interventional strategies.  
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19 51 **Methods and analysis:** Prospective cohort study that will recruit 408 women at first  
20 52 antenatal visit at <12 weeks gestation. Baseline bio-socio-demographic factors and PA levels  
21 53 assessed by participant characteristics form and the International Physical Activity  
22 54 Questionnaire (IPAQ) respectively. An activity tracker (Fitbit) will be provided to be worn  
23 55 daily from date of recruitment to end of 20 weeks gestation. Tracker-recorded data will be  
24 56 synchronized with an application on participant's smartphone. Compliance will be reinforced  
25 57 with fortnightly reminders. After 20 weeks, a second IPAQ and a feedback form will be  
26 58 administered. GDM screened at 24-28 weeks gestation. GH diagnosed after 20 weeks  
27 59 gestation. Maternal weight assessed at 6 weeks post-delivery. Appropriate statistical tests will  
28 60 be used to compare continuous and categorical PA measurements between first and second  
29 61 trimesters. Logistic regression will be used to analyse associations.  
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33 63 **Ethics and dissemination:** Ethical approval obtained from the Centralised Institutional  
34 64 Review Board of SingHealth (reference 2017/2836). Dissemination of results will be via  
35 65 peer-reviewed research publications both online and in print, conference presentations,  
36 66 posters, and medical forums.  
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40 68 (299 words)  
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44 70 **Keywords:** Physical activity, gestational diabetes mellitus, pregnancy-induced hypertension,  
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79 Article summary

80 **Strengths and limitations of this study**

- 81 • Prospective cohort study of a multi-ethnic Asian population
- 82 • Objective measurement of PA levels and patterns in early pregnancy
- 83 • Data collection designed to minimize recall bias
- 84 • Participant non-compliance despite reinforcement measures
- 85 • Participants' unfamiliarity with wearable activity tracker and mobile application
- 86 despite education at recruitment

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## 111 Introduction

112 Physical activity (PA) is defined as any bodily movement produced by skeletal muscles that  
113 results in energy expenditure<sup>1</sup>. Current recommendations encourage women with  
114 uncomplicated pregnancies to continue or initiate safe physical activities in pregnancy<sup>2</sup>. More  
115 specifically, the CDC recommends 30 min/day for five days each week of moderate-intensity  
116 aerobic activity, which can be met by walking<sup>3</sup>. Concerns about safety have been refuted by  
117 literature demonstrating that moderate exercise in low-risk pregnancy improves maternal  
118 well-being without associated risks of birth weight reduction or preterm birth<sup>4</sup>.

119 Physical inactivity or sedentary behavior in early pregnancy (<20 weeks gestation) is a  
120 potential modifiable risk factor for two common obstetric complications, gestational diabetes  
121 mellitus (GDM) and gestational hypertension (GH). GDM is defined as carbohydrate  
122 intolerance that develops during pregnancy<sup>5</sup>. It complicates 1.8-25.1% of pregnancies  
123 worldwide depending on country and definition, with South-East Asia having the second  
124 highest prevalence at 8.1-18.3<sup>6</sup>. Approximately 8-20% of pregnancies are affected in  
125 Singapore<sup>7</sup>. Overall prevalence of GH, otherwise known as pregnancy-induced hypertension,  
126 is estimated at 10-12%<sup>8,9</sup>, though the local incidence has not been established. Perinatal  
127 sequelae of GDM and GH include macrosomia, neonatal hypoglycemia, preterm birth,  
128 intrauterine growth restriction (IUGR), and low APGAR scores. Both metabolic disorders are  
129 also proven risk factors of future type 2 diabetes<sup>10</sup>.

130 Current literature investigating the association between PA in early pregnancy and the  
131 development of GDM has shown a significant risk reduction of up to 24%<sup>11-14</sup>, though a few  
132 other studies have found a null association or insufficient evidence<sup>15-17</sup>. The association with  
133 GH is even less clear from the limited literature available<sup>18-21</sup>. All these studies utilised  
134 questionnaires as a measurement of PA. Studies that incorporate an objective means of  
135 measurement have been scarce<sup>22,23</sup>, which may partially explain the inconclusive evidence of  
136 association thus far. A Norway-based study investigating objectively recorded PA in early  
137 pregnancy and GDM reported that the adjusted odds ratio for GDM decreased 19% with  
138 every 3159 step-increase per day<sup>22</sup>. Based on these existing studies, physical inactivity in  
139 early pregnancy is a modifiable risk factor worth targeting

140 This is especially so in the Asian population. PA during first half of pregnancy has been  
141 shown to be low in an Asian urban setting<sup>24</sup>, and similarly lower when compared to non-  
142 Asian counterparts<sup>23,25</sup>. In Singapore, no published study on objectively measured PA levels  
143 in pregnancy could be found, and studies on association of subjectively-measured early  
144 pregnancy PA levels with both obstetric complications are rare. Padmapriya *et al.*  
145 investigated the change in PA levels from a pre-pregnancy to pregnancy state using a  
146 structured self-constructed questionnaire administered at 26-28 weeks gestation scored based  
147 on the International Physical Activity Questionnaire (IPAQ) short form<sup>26</sup>. The same study  
148 group further reported that a higher PA during the first 6 months of pregnancy was associated  
149 with lower prevalence of GDM, especially among overweight/obese women<sup>27</sup>. However, the  
150 utilisation of a questionnaire at 26-28 weeks gestation that relied on recall of PA levels  
151 during first 6 months of pregnancy and the year before subjected the results to a high level of  
152 recall bias. Therefore, the paucity of local research on objectively-measured PA levels in  
153 early pregnancy and association with obstetric metabolic outcomes warrants additional  
154 prospective studies.



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3 155 As evident from existing studies, current assessment of pregnancy PA levels relies heavily on  
4 156 subjective, self-reporting questionnaires deemed to be the most feasible method with the  
5 157 absence of a gold standard and clear guidelines<sup>28</sup>. The inclusion of more objective  
6 158 measurements is being advocated<sup>29</sup>. Consumer wearable activity trackers operate through a 3-  
7 159 axis accelerometer, providing an alternative convenient and objective means of assessing PA  
8 160 levels during pregnancy. The accuracy, reliability and efficacy of wearable activity trackers  
9 161 in various health programs have been validated<sup>30-33</sup>, although a systematic review has found  
10 162 the research-grade accelerometer or pedometer to be superior in terms of accuracy<sup>34</sup>. Steps  
11 163 per day categorization along a physical inactivity/activity continuum based on CDC  
12 164 recommendation has also been elucidated, with 5000 (sedentary) and 10,000 (active) being  
13 165 the primary anchor points<sup>35</sup>. The correlation between steps per day and activity counts per  
14 166 day, from which activity intensity and duration were derived, was proven to be positive and  
15 167 strong, thus validating its use as an index for PA<sup>36</sup>. Step count estimated by Fitbit activity  
16 168 trackers among healthy adults has also been validated in a separate study<sup>37</sup>. Furthermore,  
17 169 various measured parameters such as step count and moderate-to-vigorous PA (MVPA) of  
18 170 different Fitbit activity trackers models have also been validated in the particular population  
19 171 of pregnant women in free living conditions<sup>38</sup>.

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25 172 Through the use of both Fitbit activity trackers and the IPAQ, this prospective multi-ethnic  
26 173 cohort study primarily aims to investigate the PA levels and patterns in early pregnancy (1st  
27 174 trimester and 2nd trimester up to 20 weeks gestation), as well as the effect of PA in early  
28 175 pregnancy on development of GDM and/or GH. Secondary aims include assessing the bio-  
29 176 socio-demographic factors associated with sedentary behavior, and examining the association  
30 177 between early pregnancy PA level and maternal weight at 6 weeks post-delivery.

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3 193 Methods and analysis  
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5 194 **Study design**  
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7 195 In this prospective cohort study, pregnant women will be recruited at outpatient clinics in KK  
8 196 Women's and Children's Hospital, a major public hospital in Singapore that sees a high  
9 197 volume of obstetrics & gynaecology consultations. Recruitment started in June 2018 and is  
10 198 expected to end in 2019. This study will follow the Strengthening the Reporting of  
11 199 Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies.  
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16 201 **Recruitment and eligibility criteria**  
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18 202 All obstetricians running outpatient general obstetrics & gynaecology clinics will refer  
19 203 suitable candidates for recruitment. All recruitment will be done via face-to-face contact by  
20 204 the research team.

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22 205 Inclusion criteria are singleton pregnancy, first antenatal visit less than 12 weeks gestation,  
23 206 and ages between 21 and 50 years old inclusive. Exclusion criteria are severe medical and/or  
24 207 psychological co-morbidity (including New York Heart Association (NYHA) class IV heart  
25 208 failure, end-stage renal disease, assistive device-dependent for mobility, cognitive  
26 209 impairment, and loss of rational thinking), and skin conditions (including contact dermatitis,  
27 210 pemphigus vulgaris and bullous pemphigoid) precluding the wearing of activity trackers.  
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32 212 **Power analysis**  
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34 213 Given that prevalence of GH has not been investigated in Singapore, GDM prevalence is  
35 214 used instead. Assuming that GDM proportion is 17.6%<sup>39</sup> and that PA can reduce risk of  
36 215 GDM by 30%, a sample of 367 mothers will be required at 80% power and 5% level of  
37 216 significance. Assuming a dropout rate of 10%, a sample of 408 mothers will be recruited into  
38 217 the study.  
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43 219 **Participant timeline**  
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45 220 Recruitment is at first antenatal visit less than 12 weeks gestation, during which Fitbit  
46 221 education, International Physical Activity Questionnaire (IPAQ) and participant  
47 222 characteristics form are done (Fig. 1). PA level monitoring occurs henceforth until end of 20  
48 223 weeks gestation inclusive. The standard 4-weekly antenatal visits will continue during this  
49 224 period. After 20 weeks gestation, a second IPAQ and a feedback form are administered either  
50 225 at regular antenatal visits before 24 weeks gestation, or over the phone/email. Routine GDM  
51 226 screening takes place between 24 and 28 weeks gestation. The final follow-up occurs at the  
52 227 6th week after delivery to obtain participants' weight.  
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57 229 **Ensuring compliance**  
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230 Approaches to enhance compliance include reinforcing the importance of commitment to  
231 wearing the activity trackers daily at the time of recruitment, and making fortnightly follow-  
232 up calls up until 20 weeks gestation. Compliance will also be recorded as part of Fitbit use  
233 assessment in the participant feedback form at the end of 20 weeks gestation.

234

## 235 **Outcome measures**

236 Primary outcomes include the following:

- 237 · GDM – diagnosed if the following threshold value at any time point is exceeded after  
238 a 75 g oral glucose tolerance test (OGTT) between 24 and 28 weeks gestation based  
239 on the International Association of Diabetes and Pregnancy Study Groups (IADPSG)  
240 criteria: fasting venous plasma glucose of  $\geq 5.1$  mmol/L, 1-hour venous plasma  
241 glucose of  $\geq 10.0$  mmol/L, and 2-hour venous plasma glucose  $\geq 8.5$  mmol/L<sup>40</sup>.
- 242 · GH – diagnosed as new onset hypertension (systolic blood pressure  $\geq 140$  mmHg  
243 and/or diastolic blood pressure  $\geq 90$  mmHg) measured on two occasions at least four  
244 hours apart after 20 weeks gestation in the absence of proteinuria or new signs of end-  
245 organ dysfunction<sup>41</sup>.

246 Secondary outcomes include the following:

- 247 · Weight at 6 weeks post-delivery
- 248 · Weight gain in pregnancy
- 249 · Intrauterine growth restriction (IUGR)
- 250 · Preterm birth (GA  $< 37$  weeks)
- 251 · Macrosomia (BW  $> 4.5$  kg)
- 252 · Neonatal hypoglycemia (glucose  $< 2.5$  mmol/L)
- 253 · Pre-eclampsia
- 254 · APGAR scores

255

## 256 **Data collection**

### 257 ***Research participant characteristics form***

258 Sociodemographic data to be assessed include marital status, educational level, household  
259 income, type of housing, working status during pregnancy, smoking status, and alcohol  
260 consumption. Medical history including pre-pregnancy height and weight, parity, history of  
261 infertility treatment, existing chronic illnesses, history of GDM and/or GH, family history of  
262 DM, and reasons behind potential PA restriction during early pregnancy will also be  
263 collected.

264

### 265 ***Fitbit activity tracker and mobile application***

266 At recruitment, each participant is given a wristband activity tracker (Fitbit) that will be  
267 connected via Bluetooth to a Fitbit application downloaded onto her smartphone. Education  
268 on device and application will be carried out. The tracker is worn daily from recruitment to

269 end of 20 weeks gestation inclusive, except during bathing or water activities. Participants are  
270 advised to synchronize the tracker data at least once a week. For data to be valid, wear-time  
271 must be at least 4 days per week (including one weekend day) and at least 10 hours per day.

272 Steps per day will be recorded by the tracker. Data will be reported as continuous and  
273 categorical variables. Continuous variables include mean weekday and weekend steps per day  
274 and mean steps per day in first and second trimesters. Categorical variables include  
275 classification into a CDC recommendation-based steps per day physical inactivity/activity  
276 continuum defined as follows: (1) <5000 (sedentary); (2) 5000-7499 (low active); (3) 7500-  
277 9999 (somewhat active); (4) 10,000-12,499 (active); and (5)  $\geq 12,500$  (highly active)<sup>35</sup>.

278

### 279 ***International Physical Activity Questionnaire (IPAQ)***

280 The IPAQ long version will be self-administered during the first visit at less than 12 weeks  
281 gestation in the first trimester and again between 20-24 weeks gestation in the second  
282 trimester. It is a set of 4 questionnaires assessing 5 activity domains (occupation,  
283 transportation, household, leisure, and sedentary) independently in the past 7 days, and may  
284 be administered via self or telephone<sup>42</sup>. Well-established and validated in adults aged 15-69  
285 years, it is available in both English and Chinese<sup>43,44</sup>. It has been used in studies involving  
286 pregnant women<sup>29,45</sup>.

287 Data will be reported as continuous and categorical variables. Continuous variables include  
288 median MET-minutes per week (MET-min/wk) and interquartile ranges computed for each  
289 domain, subdomain (walking, moderate-intensity PA and vigorous-intensity PA) and overall  
290 total PA. MET or metabolic equivalent is a unit that measures energy expenditure in  
291 multiples of the resting metabolic rate<sup>46</sup>. Categorical variables include classification into low,  
292 moderate, high levels of PA according to the IPAQ scoring protocol.

293

### 294 ***Medical record data***

295 Additional data to be collected include ethnicity, weight changes during pregnancy, weight at  
296 6 weeks post-delivery, obstetric outcomes of GDM, GH, preeclampsia and IUGR, and  
297 neonatal outcomes comprising APGAR scores, preterm birth, macrosomia, and neonatal  
298 hypoglycemia.

299

### 300 ***Participant feedback form***

301 After the end of 20 weeks gestation, experience with the activity tracker and mobile  
302 application in terms of usability and troubleshooting will be evaluated. Compliance level will  
303 be quantified by number of days per week.

304

### 305 **Statistics**

306 Descriptive statistics of PA levels in the 1st and early 2nd trimester will be presented.  
307 Categorical variables will be presented as n (%) while continuous variables will be presented

308 as mean (SD) or median (SD). Mean steps per day and median MET-minutes per week  
309 between semesters will be compared using paired Student's t-test and Wilcoxon signed-rank  
310 test respectively. McNemar's test will be used to compare sedentary behavior between  
311 semesters. Similar tests will be employed to assess for a difference in PA levels between  
312 weekdays and weekends.

313 Binary logistic regression will be used to evaluate the association of early pregnancy PA with  
314 GDM and/or GH. Crude (unadjusted) and adjusted regression models will be included.  
315 Potential confounders will be identified a priori based on literature review and controlled for  
316 in the regression analyses. Potential interactions between covariates and early pregnancy PA  
317 will be tested using cross-product terms. Secondary analyses on the bio-socio-demographic  
318 factors associated with sedentary behavior, as well as the association between early  
319 pregnancy PA level and maternal weight at 6 weeks post-delivery, will follow the methods of  
320 the primary analyses, but are exploratory having not been powered to formally test the  
321 hypotheses. All regression analyses will be presented as odds ratios (ORs) with 95%  
322 confidence intervals (CIs).

323 Statistical analyses will be performed using IBM SPSS Statistics version 23.0 (IBM Corp.,  
324 Armonk, N.Y., USA). *P* values of <0.05 will be considered statistically significant.

325

### 326 **Safety parameters**

327 Adverse effects and device monitoring will be carried out at the subsequent 4-weekly routine  
328 prenatal visits. Any adverse skin reaction to the wristband will be recorded. Participation will  
329 be stopped at any time the Principal Investigator decides that continuing on could be harmful  
330 to the participant.

331

### 332 **Data management**

333 All data will be coded for confidentiality. Hardcopy data will be stored at the research site  
334 under lock and key. Electronic data can only be accessed and retrieved from the secured  
335 website by the participant and research team. Electronic data will be exported on a fortnightly  
336 basis. All data obtained will be entered into and stored on the institution Research Electronic  
337 Data Capture (REDCap) system, a centralised secured data management server with  
338 password access. Data integrity monitoring will be carried out monthly by the principal  
339 investigator and co-investigators if deemed necessary.

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### 341 **Patient and Public Involvement**

342 Patients and the public were not involved in the development of the research question and  
343 outcome measures.

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3 347 Ethics and dissemination  
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5 348 Ethical approval was obtained from the Centralised Institutional Review Board of SingHealth  
6 349 (reference 2017/2836). Informed written consent will be sought from all participants.  
7

8 350 Results from this study will be submitted to the funding organization and peer-reviewed  
9 351 journals for consideration of publication both online and in print. Results will also be  
10 352 presented at relevant meetings, conferences and medical forums in either oral or poster  
11 353 formats.  
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3 379 Conclusion  
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5 380 The I-ACT study aims to be the first comprehensive study objectively evaluating the PA  
6 381 levels and patterns in early pregnancy, and their association with GDM and/or GH in the  
7 382 multi-ethnic population of Singapore. In addition to addressing these important scientific  
8 383 knowledge gaps, from a clinical perspective, the study itself may increase awareness of PA  
9 384 during early pregnancy while demonstrating the potential of wearable activity trackers as an  
10 385 objective measure of PA in health research. More importantly, we hope the results of the  
11 386 study facilitate the identification of high-risk mothers-to-be for targeted intervention, and  
12 387 help formulate strategies for interventional efforts.  
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5 591 MC was involved in all aspects of the study from conception, design, recruitment and  
6 592 manuscript writing. KHT and SBA provided critical review of the design and writing. As  
7 593 Principle Investigator, SBA takes overall responsibility for the work. All authors agree to be  
8 594 accountable for their work.  
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21 602 Conflict of interests

22  
23 603 The authors declare no potential conflicts of interest with respect to the authorship and/or  
24 604 publication of this article.  
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32 608 Figure Legend

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34 609 Figure 1. Timeline of the I-ACT prospective cohort study.

35 610 †Participants will continue to attend routine antenatal visits throughout the study period  
36 611 during which blood pressure monitoring will be done.  
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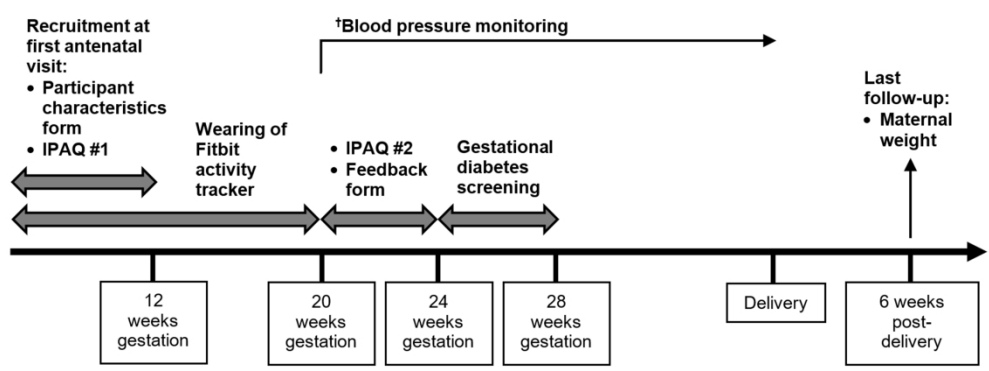


Figure 1. Timeline of the I-ACT prospective cohort study.  
 †Participants will continue to attend routine antenatal visits throughout the study period during which blood pressure monitoring will be done.

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# BMJ Open

## I-ACT: Integrated study on effect of Activity on ComplicaTions in pregnancy – study protocol of a multi-ethnic prospective cohort study

Journal:	<i>BMJ Open</i>
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Secondary Subject Heading:	General practice / Family practice, Diabetes and endocrinology
Keywords:	Diabetes in pregnancy < DIABETES & ENDOCRINOLOGY, Maternal medicine < OBSTETRICS, PREVENTIVE MEDICINE, PRIMARY CARE

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Manuscripts

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10 **3** I-ACT: Integrated study on effect of Activity on ComplicaTions in  
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3 38 Abstract  
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5 39 **Introduction:** Physical activity (PA) during first 20 weeks of pregnancy may lower risks of  
6 40 gestational diabetes mellitus (GDM) and gestational hypertension (GH), though evidence of  
7 41 association remains inconclusive. Current studies rely heavily on subjective assessment of PA  
8 42 levels. Wearable activity trackers provide a convenient and objective surrogate index for PA  
9 43 validated by evidence-based steps/day categorization along a physical inactivity/activity  
10 44 continuum. I-ACT primarily aims to examine objectively measured PA levels and patterns in  
11 45 first and second trimesters of pregnancy and the association with GDM and/or GH in  
12 46 Singapore, a multi-ethnic Asian population. Secondary aims include investigating the bio-  
13 47 socio-demographic factors associated with sedentary behavior, and association of early  
14 48 pregnancy PA level with maternal weight at 6 weeks post-delivery. Results may facilitate  
15 49 identification of high-risk mothers-to-be and formulation of interventional strategies.  
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19 51 **Methods and analysis:** Prospective cohort study that will recruit 408 women at first  
20 52 antenatal visit at <12 weeks gestation. Baseline bio-socio-demographic factors and PA levels  
21 53 assessed by participant characteristics form and the International Physical Activity  
22 54 Questionnaire (IPAQ) respectively. An activity tracker (Fitbit) will be provided to be worn  
23 55 daily from date of recruitment to end of 20 weeks gestation. Tracker-recorded data will be  
24 56 synchronized with an application on participant's smartphone. Compliance will be reinforced  
25 57 with fortnightly reminders. After 20 weeks, a second IPAQ and a feedback form will be  
26 58 administered. GDM screened at 24-28 weeks gestation. GH diagnosed after 20 weeks  
27 59 gestation. Maternal weight assessed at 6 weeks post-delivery. Appropriate statistical tests will  
28 60 be used to compare continuous and categorical PA measurements between first and second  
29 61 trimesters. Logistic regression will be used to analyse associations.  
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33 63 **Ethics and dissemination:** Ethical approval obtained from the Centralised Institutional  
34 64 Review Board of SingHealth (reference 2017/2836). Dissemination of results will be via  
35 65 peer-reviewed research publications both online and in print, conference presentations,  
36 66 posters, and medical forums.  
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40 68 (299 words)  
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44 70 **Keywords:** Physical activity, gestational diabetes mellitus, pregnancy-induced hypertension,  
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79 Article summary

80 **Strengths and limitations of this study**

- 81 • Prospective cohort study of a multi-ethnic Asian population
- 82 • Objective measurement of PA levels and patterns in early pregnancy
- 83 • Data collection designed to minimize recall bias
- 84 • Participant non-compliance despite reinforcement measures
- 85 • Participants' unfamiliarity with wearable activity tracker and mobile application
- 86 despite education at recruitment

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## 111 Introduction

112 Physical activity (PA) is defined as any bodily movement produced by skeletal muscles that  
113 results in energy expenditure<sup>1</sup>. Current recommendations encourage women with  
114 uncomplicated pregnancies to continue or initiate safe physical activities in pregnancy<sup>2</sup>. More  
115 specifically, the CDC recommends 30 min/day for five days each week of moderate-intensity  
116 aerobic activity, which can be met by walking<sup>3</sup>. Concerns about safety have been refuted by  
117 literature demonstrating that moderate exercise in low-risk pregnancy improves maternal  
118 well-being without associated risks of birth weight reduction or preterm birth<sup>4</sup>.

119 Physical inactivity or sedentary behavior in early pregnancy (<20 weeks gestation) is a  
120 potential modifiable risk factor for two common obstetric complications, gestational diabetes  
121 mellitus (GDM) and gestational hypertension (GH). GDM is defined as carbohydrate  
122 intolerance that develops during pregnancy<sup>5</sup>. It complicates 1.8-25.1% of pregnancies  
123 worldwide depending on country and definition, with South-East Asia having the second  
124 highest prevalence at 8.1-18.3<sup>6</sup>. Approximately 8-20% of pregnancies are affected in  
125 Singapore<sup>7</sup>. Overall prevalence of GH, otherwise known as pregnancy-induced hypertension,  
126 is estimated at 10-12%<sup>8,9</sup>, though the local incidence has not been established. Perinatal  
127 sequelae of GDM and GH include macrosomia, neonatal hypoglycemia, preterm birth,  
128 intrauterine growth restriction (IUGR), and low APGAR scores. Both metabolic disorders are  
129 also proven risk factors of future type 2 diabetes<sup>10</sup>.

130 Current literature investigating the association between PA in early pregnancy and the  
131 development of GDM has shown a significant risk reduction of up to 24%<sup>11-14</sup>, though a few  
132 other studies have found a null association or insufficient evidence<sup>15-17</sup>. The association with  
133 GH is even less clear from the limited literature available<sup>18-21</sup>. All these studies utilised  
134 questionnaires as a measurement of PA. Studies that incorporate an objective means of  
135 measurement have been scarce<sup>22,23</sup>, which may partially explain the inconclusive evidence of  
136 association thus far. A Norway-based study investigating objectively recorded PA in early  
137 pregnancy and GDM reported that the adjusted odds ratio for GDM decreased 19% with  
138 every 3159 step-increase per day<sup>22</sup>. Based on these existing studies, physical inactivity in  
139 early pregnancy is a modifiable risk factor worth targeting

140 This is especially so in the Asian population. PA during first half of pregnancy has been  
141 shown to be low in an Asian urban setting<sup>24</sup>, and similarly lower when compared to non-  
142 Asian counterparts<sup>23,25</sup>. In Singapore, no published study on objectively measured PA levels  
143 in pregnancy could be found, and studies on association of subjectively-measured early  
144 pregnancy PA levels with both obstetric complications are rare. Padmapriya *et al.*  
145 investigated the change in PA levels from a pre-pregnancy to pregnancy state using a  
146 structured self-constructed questionnaire administered at 26-28 weeks gestation scored based  
147 on the International Physical Activity Questionnaire (IPAQ) short form<sup>26</sup>. The same study  
148 group further reported that a higher PA during the first 6 months of pregnancy was associated  
149 with lower prevalence of GDM, especially among overweight/obese women<sup>27</sup>. However, the  
150 utilisation of a questionnaire at 26-28 weeks gestation that relied on recall of PA levels  
151 during first 6 months of pregnancy and the year before subjected the results to a high level of  
152 recall bias. Therefore, the paucity of local research on objectively-measured PA levels in  
153 early pregnancy and association with obstetric metabolic outcomes warrants additional  
154 prospective studies.

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3 155 As evident from existing studies, current assessment of pregnancy PA levels relies heavily on  
4 156 subjective, self-reporting questionnaires deemed to be the most feasible method with the  
5 157 absence of a gold standard and clear guidelines<sup>28</sup>. The inclusion of more objective  
6 158 measurements is being advocated<sup>29</sup>. Consumer wearable activity trackers operate through a 3-  
7 159 axis accelerometer, providing an alternative convenient and objective means of assessing PA  
8 160 levels during pregnancy. The accuracy, reliability and efficacy of wearable activity trackers  
9 161 in various health programs have been validated<sup>30-33</sup>, although a systematic review has found  
10 162 the research-grade accelerometer or pedometer to be superior in terms of accuracy<sup>34</sup>. Steps  
11 163 per day categorization along a physical inactivity/activity continuum based on CDC  
12 164 recommendation has also been elucidated, with 5000 (sedentary) and 10,000 (active) being  
13 165 the primary anchor points<sup>35</sup>. The correlation between steps per day and activity counts per  
14 166 day, from which activity intensity and duration were derived, was proven to be positive and  
15 167 strong, thus validating its use as an index for PA<sup>36</sup>. Step count estimated by Fitbit activity  
16 168 trackers among healthy adults has also been validated in a separate study<sup>37</sup>. Furthermore,  
17 169 various measured parameters such as step count and moderate-to-vigorous PA (MVPA) of  
18 170 different Fitbit activity trackers models have also been validated in the particular population  
19 171 of pregnant women in free living conditions<sup>38</sup>.

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25 172 Through the use of both Fitbit activity trackers and the IPAQ, this prospective multi-ethnic  
26 173 cohort study primarily aims to investigate the PA levels and patterns in early pregnancy (1st  
27 174 trimester and 2nd trimester up to 20 weeks gestation), as well as the effect of PA in early  
28 175 pregnancy on development of GDM and/or GH. Secondary aims include assessing the bio-  
29 176 socio-demographic factors associated with sedentary behavior, and examining the association  
30 177 between early pregnancy PA level and maternal weight at 6 weeks post-delivery.

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3 193 Methods and analysis  
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5 194 **Study design**  
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7 195 In this prospective cohort study, pregnant women will be recruited at outpatient clinics in KK  
8 196 Women's and Children's Hospital, a major public hospital in Singapore that sees a high  
9 197 volume of obstetrics & gynaecology consultations. Recruitment started in June 2018 and is  
10 198 expected to end in 2019. This study will follow the Strengthening the Reporting of  
11 199 Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies.  
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16 201 **Recruitment and eligibility criteria**  
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18 202 All obstetricians running outpatient general obstetrics & gynaecology clinics will refer  
19 203 suitable candidates for recruitment. All recruitment will be done via face-to-face contact by  
20 204 the research team.  
21

22 205 Inclusion criteria are singleton pregnancy, first antenatal visit less than 12 weeks gestation,  
23 206 and ages between 21 and 50 years old inclusive. Exclusion criteria are severe medical and/or  
24 207 psychological co-morbidity (including New York Heart Association (NYHA) class IV heart  
25 208 failure, end-stage renal disease, assistive device-dependent for mobility, cognitive  
26 209 impairment, and loss of rational thinking), and skin conditions (including contact dermatitis,  
27 210 pemphigus vulgaris and bullous pemphigoid) precluding the wearing of activity trackers.  
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32 212 **Power analysis**  
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34 213 Given that prevalence of GH has not been investigated in Singapore, GDM prevalence is  
35 214 used instead. Assuming that GDM proportion is 17.6%<sup>39</sup> and that PA can reduce risk of  
36 215 GDM by 30%, a sample of 367 mothers will be required at 80% power and 5% level of  
37 216 significance. Assuming a dropout rate of 10%, a sample of 408 mothers will be recruited into  
38 217 the study.  
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43 219 **Participant timeline**  
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45 220 Recruitment is at first antenatal visit less than 12 weeks gestation, during which Fitbit  
46 221 education, International Physical Activity Questionnaire (IPAQ) and participant  
47 222 characteristics form are done (Fig. 1). PA level monitoring occurs henceforth until end of 20  
48 223 weeks gestation inclusive. The standard 4-weekly antenatal visits will continue during this  
49 224 period. After 20 weeks gestation, a second IPAQ and a feedback form are administered either  
50 225 at regular antenatal visits before 24 weeks gestation, or over the phone/email. Routine GDM  
51 226 screening takes place between 24 and 28 weeks gestation. The final follow-up occurs at the  
52 227 6th week after delivery to obtain participants' weight.  
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57 229 **Ensuring compliance**  
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230 Approaches to enhance compliance include reinforcing the importance of commitment to  
231 wearing the activity trackers daily at the time of recruitment, and making fortnightly follow-  
232 up calls up until 20 weeks gestation. Compliance will also be recorded as part of Fitbit use  
233 assessment in the participant feedback form at the end of 20 weeks gestation.

234

## 235 **Outcome measures**

236 Primary outcomes include the following:

- 237 · GDM – diagnosed if the following threshold value at any time point is exceeded after  
238 a 75 g oral glucose tolerance test (OGTT) between 24 and 28 weeks gestation based  
239 on the International Association of Diabetes and Pregnancy Study Groups (IADPSG)  
240 criteria: fasting venous plasma glucose of  $\geq 5.1$  mmol/L, 1-hour venous plasma  
241 glucose of  $\geq 10.0$  mmol/L, and 2-hour venous plasma glucose  $\geq 8.5$  mmol/L<sup>40</sup>.
- 242 · GH – diagnosed as new onset hypertension (systolic blood pressure  $\geq 140$  mmHg  
243 and/or diastolic blood pressure  $\geq 90$  mmHg) measured on two occasions at least four  
244 hours apart after 20 weeks gestation in the absence of proteinuria or new signs of end-  
245 organ dysfunction<sup>41</sup>.

246 Secondary outcomes include the following:

- 247 · Weight at 6 weeks post-delivery
- 248 · Weight gain in pregnancy
- 249 · Intrauterine growth restriction (IUGR)
- 250 · Preterm birth (GA  $< 37$  weeks)
- 251 · Macrosomia (BW  $> 90$ th percentile or  $> 4.0$  kg)
- 252 · Neonatal hypoglycemia (glucose  $< 2.5$  mmol/L)
- 253 · Pre-eclampsia
- 254 · APGAR scores

255

## 256 **Data collection**

### 257 ***Research participant characteristics form***

258 Sociodemographic data to be assessed include marital status, educational level, household  
259 income, type of housing, working status during pregnancy, smoking status, and alcohol  
260 consumption. Medical history including pre-pregnancy height and weight, parity, history of  
261 infertility treatment, existing chronic illnesses, history of GDM and/or GH, family history of  
262 DM, and reasons behind potential PA restriction during early pregnancy will also be  
263 collected.

264

### 265 ***Fitbit activity tracker and mobile application***

266 At recruitment, each participant is given a wristband activity tracker (Fitbit) that will be  
267 connected via Bluetooth to a Fitbit application downloaded onto her smartphone. Education  
268 on device and application will be carried out. The tracker is worn daily from recruitment to

269 end of 20 weeks gestation inclusive, except during bathing or water activities. Participants are  
270 advised to synchronize the tracker data at least once a week. For data to be valid, wear-time  
271 must be at least 4 days per week (including one weekend day) and at least 10 hours per day.

272 Steps per day will be recorded by the tracker. Data will be reported as continuous and  
273 categorical variables. Continuous variables include mean weekday and weekend steps per day  
274 and mean steps per day in first and second trimesters. Categorical variables include  
275 classification into a CDC recommendation-based steps per day physical inactivity/activity  
276 continuum defined as follows: (1) <5000 (sedentary); (2) 5000-7499 (low active); (3) 7500-  
277 9999 (somewhat active); (4) 10,000-12,499 (active); and (5)  $\geq 12,500$  (highly active)<sup>35</sup>.

278

### 279 ***International Physical Activity Questionnaire (IPAQ)***

280 The IPAQ long version will be self-administered during the first visit at less than 12 weeks  
281 gestation in the first trimester and again between 20-24 weeks gestation in the second  
282 trimester. It is a set of 4 questionnaires assessing 5 activity domains (occupation,  
283 transportation, household, leisure, and sedentary) independently in the past 7 days, and may  
284 be administered via self or telephone<sup>42</sup>. Well-established and validated in adults aged 15-69  
285 years, it is available in both English and Chinese<sup>43,44</sup>. It has been used in studies involving  
286 pregnant women<sup>29,45</sup>.

287 Data will be reported as continuous and categorical variables. Continuous variables include  
288 median MET-minutes per week (MET-min/wk) and interquartile ranges computed for each  
289 domain, subdomain (walking, moderate-intensity PA and vigorous-intensity PA) and overall  
290 total PA. MET or metabolic equivalent is a unit that measures energy expenditure in  
291 multiples of the resting metabolic rate<sup>46</sup>. Categorical variables include classification into low,  
292 moderate, high levels of PA according to the IPAQ scoring protocol.

293

### 294 ***Medical record data***

295 Additional data to be collected include ethnicity, weight changes during pregnancy, weight at  
296 6 weeks post-delivery, obstetric outcomes of GDM, GH, preeclampsia and IUGR, and  
297 neonatal outcomes comprising APGAR scores, preterm birth, macrosomia, and neonatal  
298 hypoglycemia.

299

### 300 ***Participant feedback form***

301 After the end of 20 weeks gestation, experience with the activity tracker and mobile  
302 application in terms of usability and troubleshooting will be evaluated. Compliance level will  
303 be quantified by number of days per week.

304

### 305 **Statistics**

306 Descriptive statistics of PA levels in the 1st and early 2nd trimester will be presented.  
307 Categorical variables will be presented as n (%) while continuous variables will be presented

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3 308 as mean (SD) or median (IQR). Mean steps per day and median MET-minutes per week  
4 309 between semesters will be compared using paired Student's t-test and Wilcoxon signed-rank  
5 310 test respectively. McNemar's test will be used to compare sedentary behavior between  
6 311 semesters. Similar tests will be employed to assess for a difference in PA levels between  
7 312 weekdays and weekends.

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10 313 Binary logistic regression will be used to evaluate the association of early pregnancy PA with  
11 314 GDM and/or GH. Crude (unadjusted) and adjusted regression models will be included.  
12 315 Potential confounders will be identified a priori based on literature review and controlled for  
13 316 in the regression analyses. Potential interactions between covariates and early pregnancy PA  
14 317 will be tested using cross-product terms. Secondary analyses on the bio-socio-demographic  
15 318 factors associated with sedentary behavior, as well as the association between early  
16 319 pregnancy PA level and maternal weight at 6 weeks post-delivery, will follow the methods of  
17 320 the primary analyses, but are exploratory having not been powered to formally test the  
18 321 hypotheses. All regression analyses will be presented as odds ratios (ORs) with 95%  
19 322 confidence intervals (CIs).

20 323 Statistical analyses will be performed using IBM SPSS Statistics version 23.0 (IBM Corp.,  
21 324 Armonk, N.Y., USA). *P* values of <0.05 will be considered statistically significant.

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### 27 28 326 **Safety parameters**

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30 327 Adverse effects and device monitoring will be carried out at the subsequent 4-weekly routine  
31 328 prenatal visits. Any adverse skin reaction to the wristband will be recorded. Participation will  
32 329 be stopped at any time the Principal Investigator decides that continuing on could be harmful  
33 330 to the participant.

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### 35 36 37 332 **Data management**

38  
39 333 All data will be coded for confidentiality. Hardcopy data will be stored at the research site  
40 334 under lock and key. Electronic data can only be accessed and retrieved from the secured  
41 335 website by the participant and research team. Electronic data will be exported on a fortnightly  
42 336 basis. All data obtained will be entered into and stored on the institution Research Electronic  
43 337 Data Capture (REDCap) system, a centralised secured data management server with  
44 338 password access. Data integrity monitoring will be carried out monthly by the principal  
45 339 investigator and co-investigators if deemed necessary.

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### 50 341 **Patient and Public Involvement**

51 342 Patients and the public were not involved in the development of the research question and  
52 343 outcome measures.

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3 347 Ethics and dissemination  
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5 348 Ethical approval was obtained from the Centralised Institutional Review Board of SingHealth  
6 349 (reference 2017/2836). Informed written consent will be sought from all participants.  
7

8 350 Results from this study will be submitted to the funding organization and peer-reviewed  
9 351 journals for consideration of publication both online and in print. Results will also be  
10 352 presented at relevant meetings, conferences and medical forums in either oral or poster  
11 353 formats.  
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3 379 Conclusion  
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5 380 The I-ACT study aims to be the first comprehensive study objectively evaluating the PA  
6 381 levels and patterns in early pregnancy, and their association with GDM and/or GH in the  
7 382 multi-ethnic population of Singapore. In addition to addressing these important scientific  
8 383 knowledge gaps, from a clinical perspective, the study itself may increase awareness of PA  
9 384 during early pregnancy while demonstrating the potential of wearable activity trackers as an  
10 385 objective measure of PA in health research. More importantly, we hope the results of the  
11 386 study facilitate the identification of high-risk mothers-to-be for targeted intervention, and  
12 387 help formulate strategies for interventional efforts.  
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6 414 advice during the conception of this study.  
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3 590 Author statement  
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5 591 MC was involved in all aspects of the study from conception, design, recruitment and  
6 592 manuscript writing. KHT and SBA provided critical review of the design and writing. As  
7 593 Principle Investigator, SBA takes overall responsibility for the work. All authors agree to be  
8 594 accountable for their work.  
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20  
21 602 Conflict of interests  
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23 603 The authors declare no potential conflicts of interest with respect to the authorship and/or  
24 604 publication of this article.  
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28 606 Word Count: 2415  
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30 607

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32 608 Figure Legend  
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34 609 Figure 1. Timeline of the I-ACT prospective cohort study.

35 610 †Participants will continue to attend routine antenatal visits throughout the study period  
36 611 during which blood pressure monitoring will be done.  
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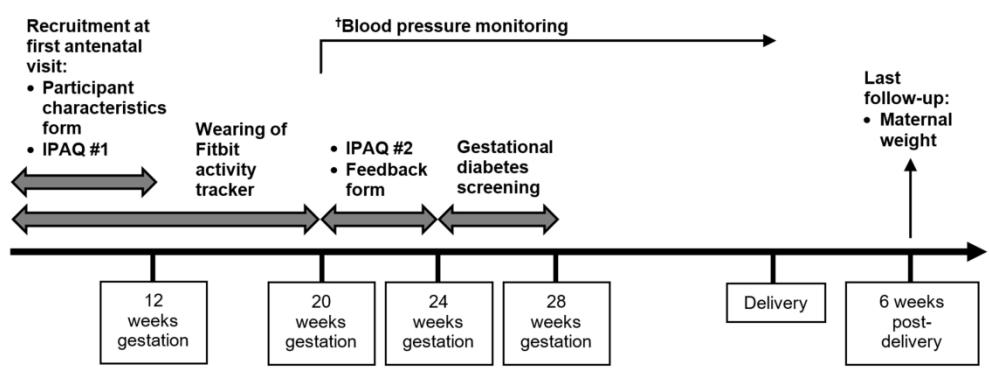


Figure 1. Timeline of the I-ACT prospective cohort study.  
 †Participants will continue to attend routine antenatal visits throughout the study period during which blood pressure monitoring will be done.

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